Magnetic control of laser ablation plasma for high-flux ion injectors

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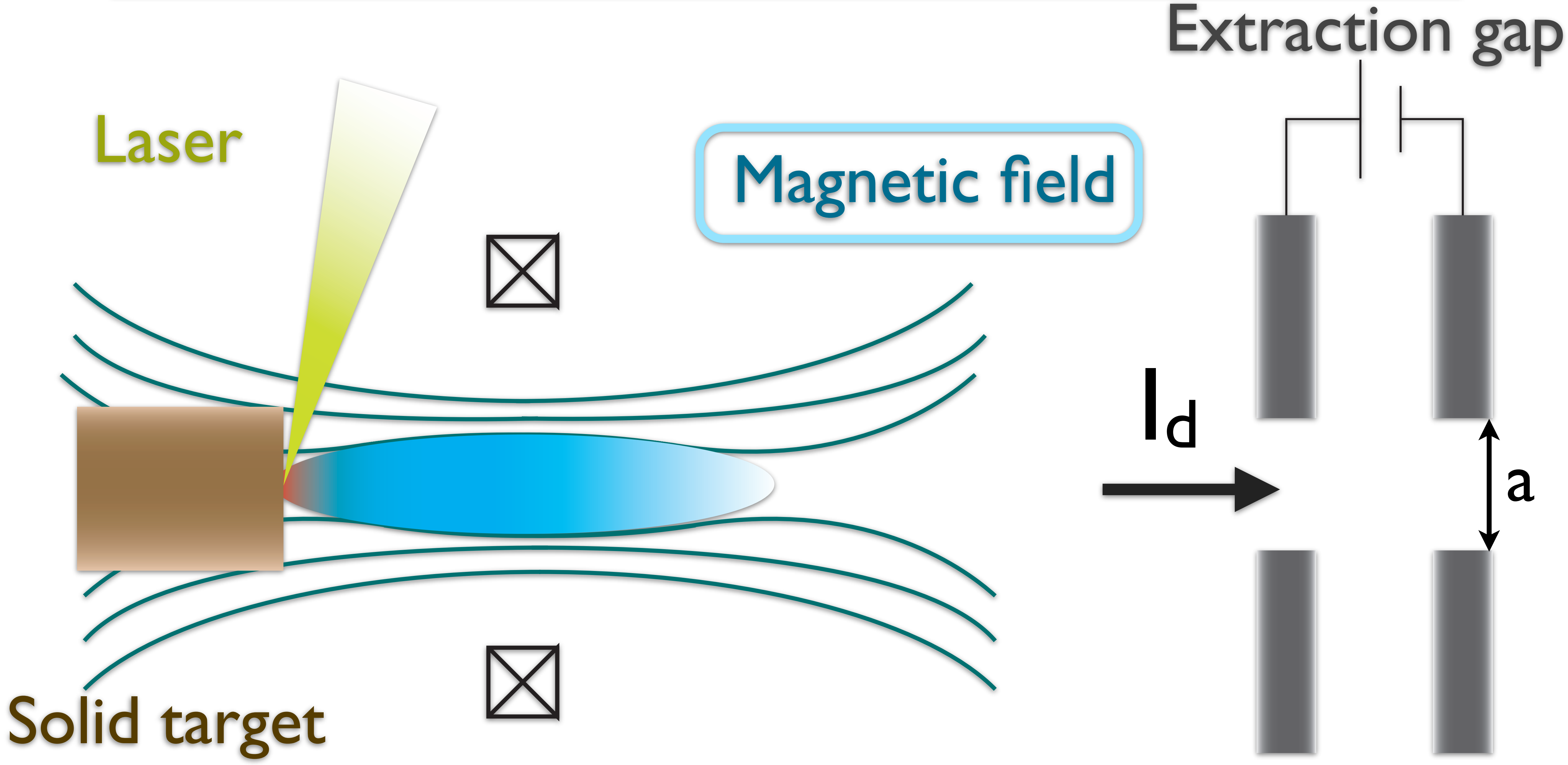
Magnetically controlled laser ablation plasma can be applied for high-flux ion injector



High drift velocity u
Low ion temperature T

Large supply current I_d
Low emittance ε

Advantages of magnetically controlled ablation plasma

- Laser ablation plasma has high drift velocity and low temperature after adiabatic expansion.

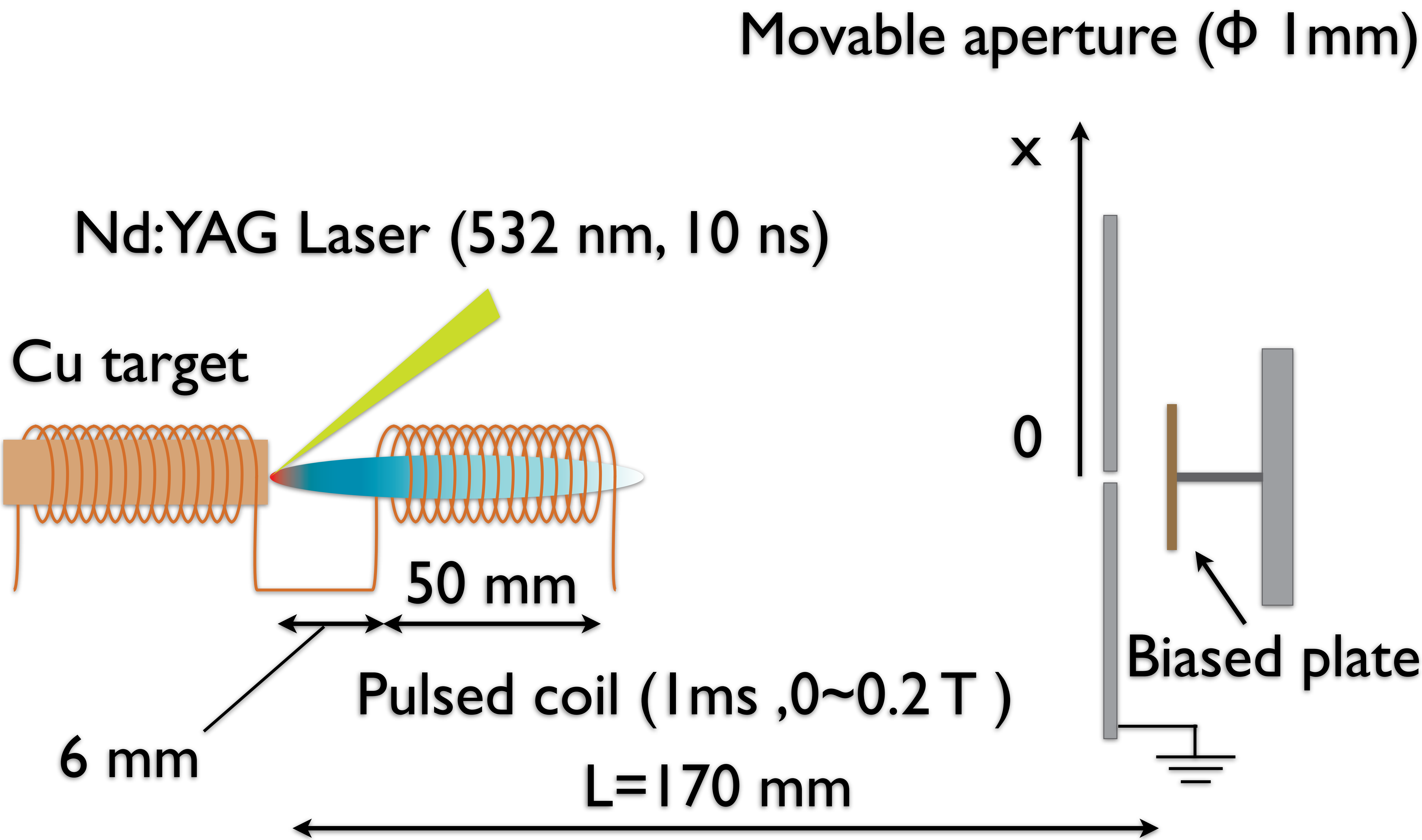
→ high-flux and low-emittance ion injector.

$$(I_d = aZenu \text{ and } \varepsilon = a(kT/mc^2)^{1/2})$$

- To supply directional and high flux plasma to the extractor, we introduced Magnetic field guiding for expanding plume.

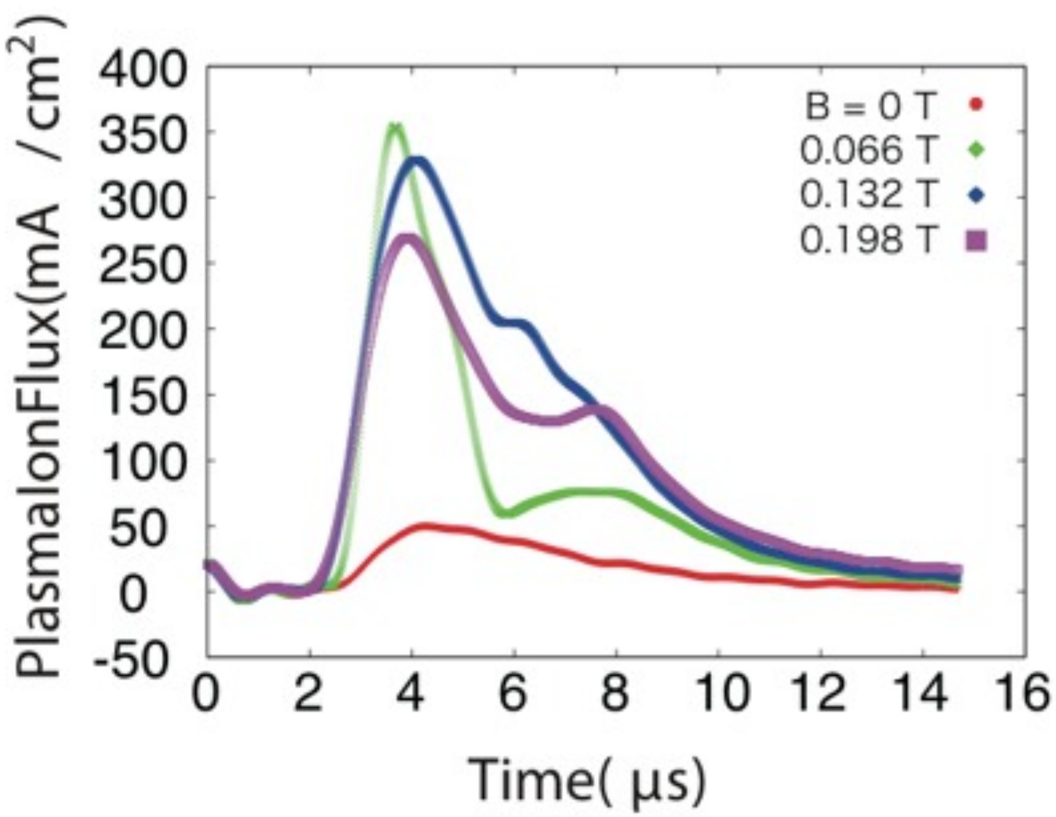
It was found that weak (0.1 T) magnetic field
(plasma pressure ~10MPa >> magnetic pressure ~10kPa)
can modify plasma flux of ions.

Longitudinal magnetic field was applied to the ablation plasma

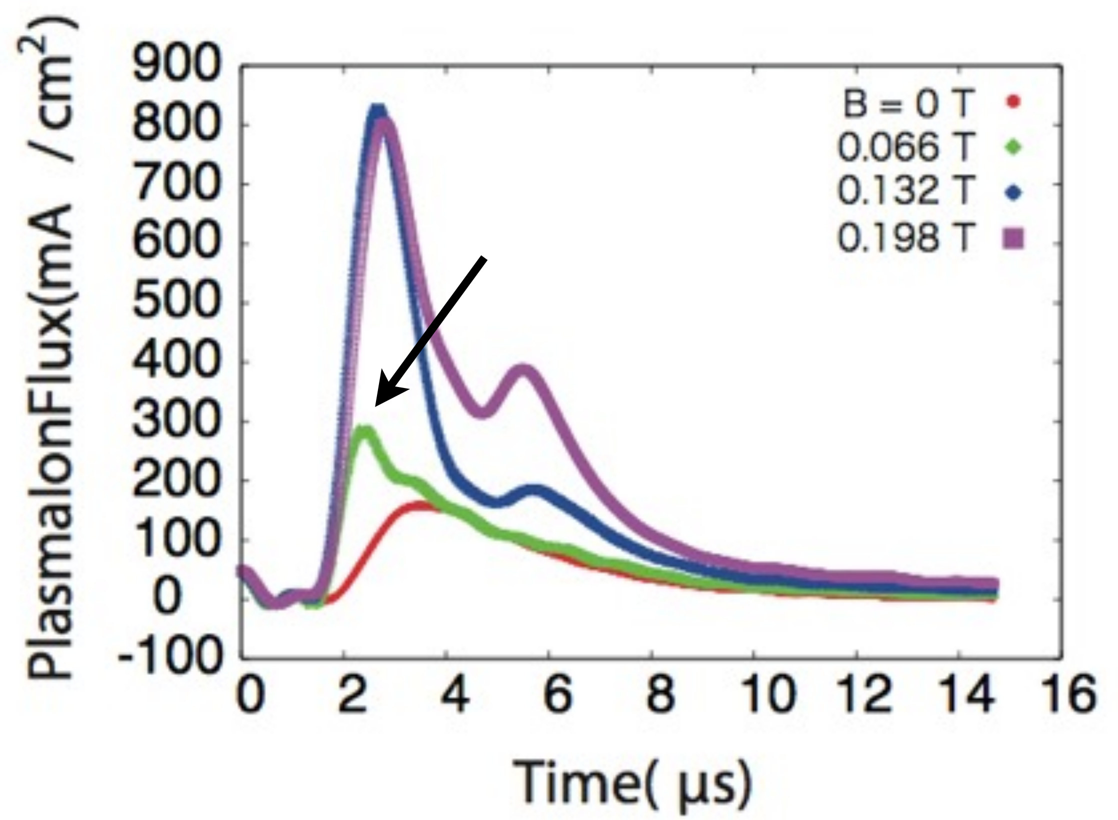


The plasma ion flux on the axis as a function of the magnetic flux density and laser intensity

(a) $E_L = 3.2 \times 10^8$ W/cm^2

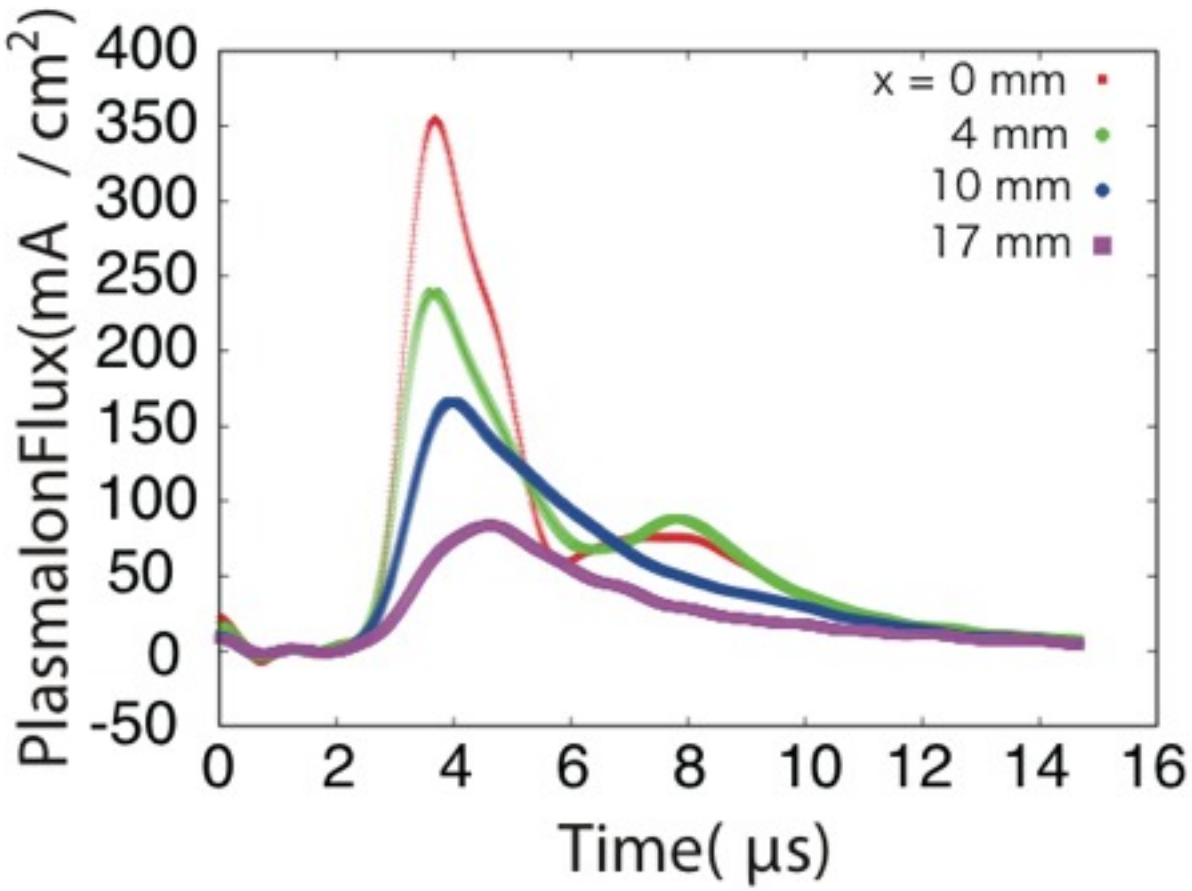


(b) $E_L = 9.5 \times 10^8$ W/cm^2



- Additional fast peak appeared with weak magnetic field.
- Arrival time of fast peak increased with magnetic field.
- Fast peak increased (5-7 times), then decreased slowly and became wider with increasing magnetic field.
- Slow peak appeared and increased with magnetic field.

The plasma ion flux as a function of the transverse distance r



$B = 0.066$ T

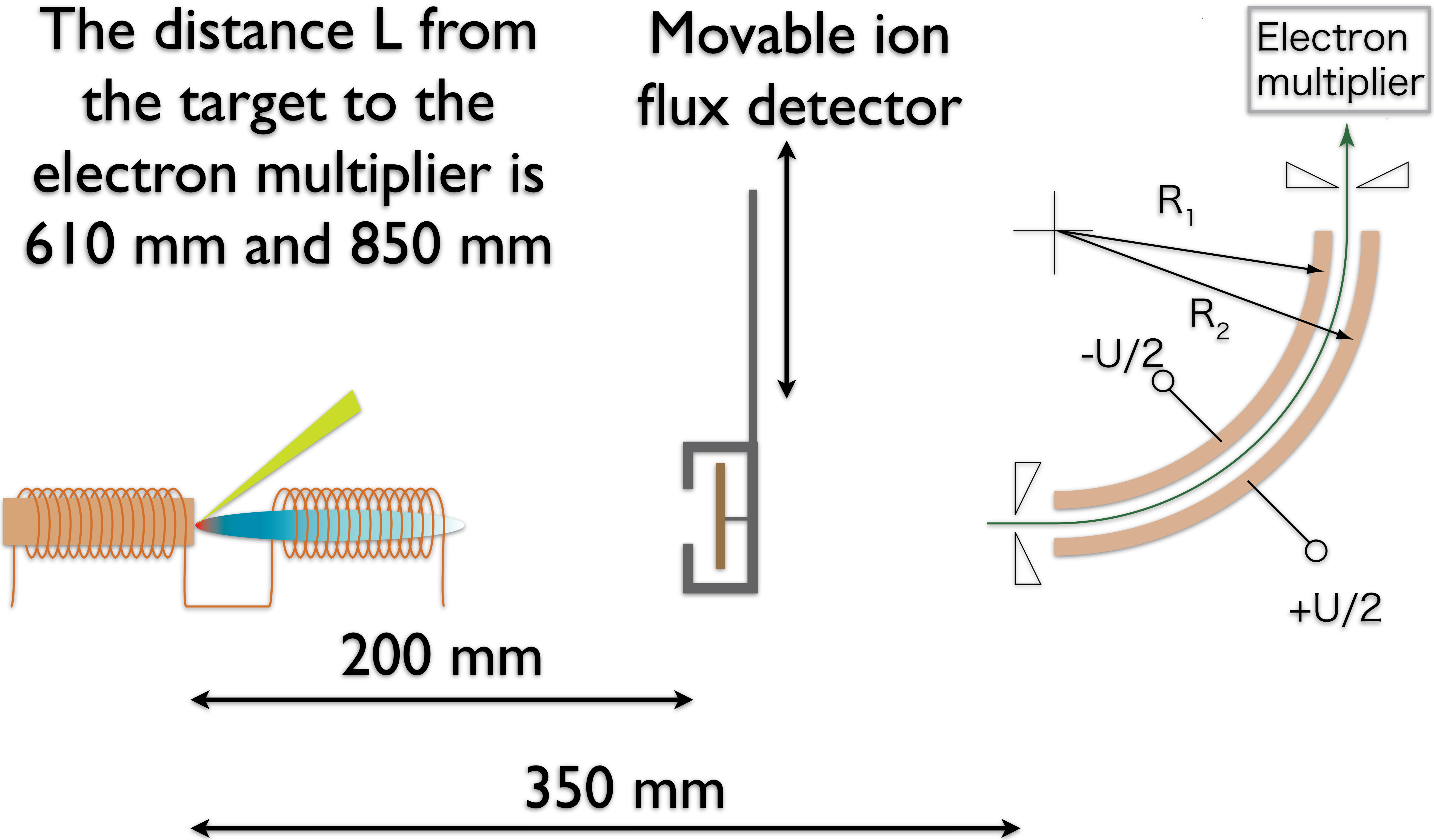
$E_L = 3.2 \times 10^8$ W/cm^2

r = 0-17mm (0-5.7°)

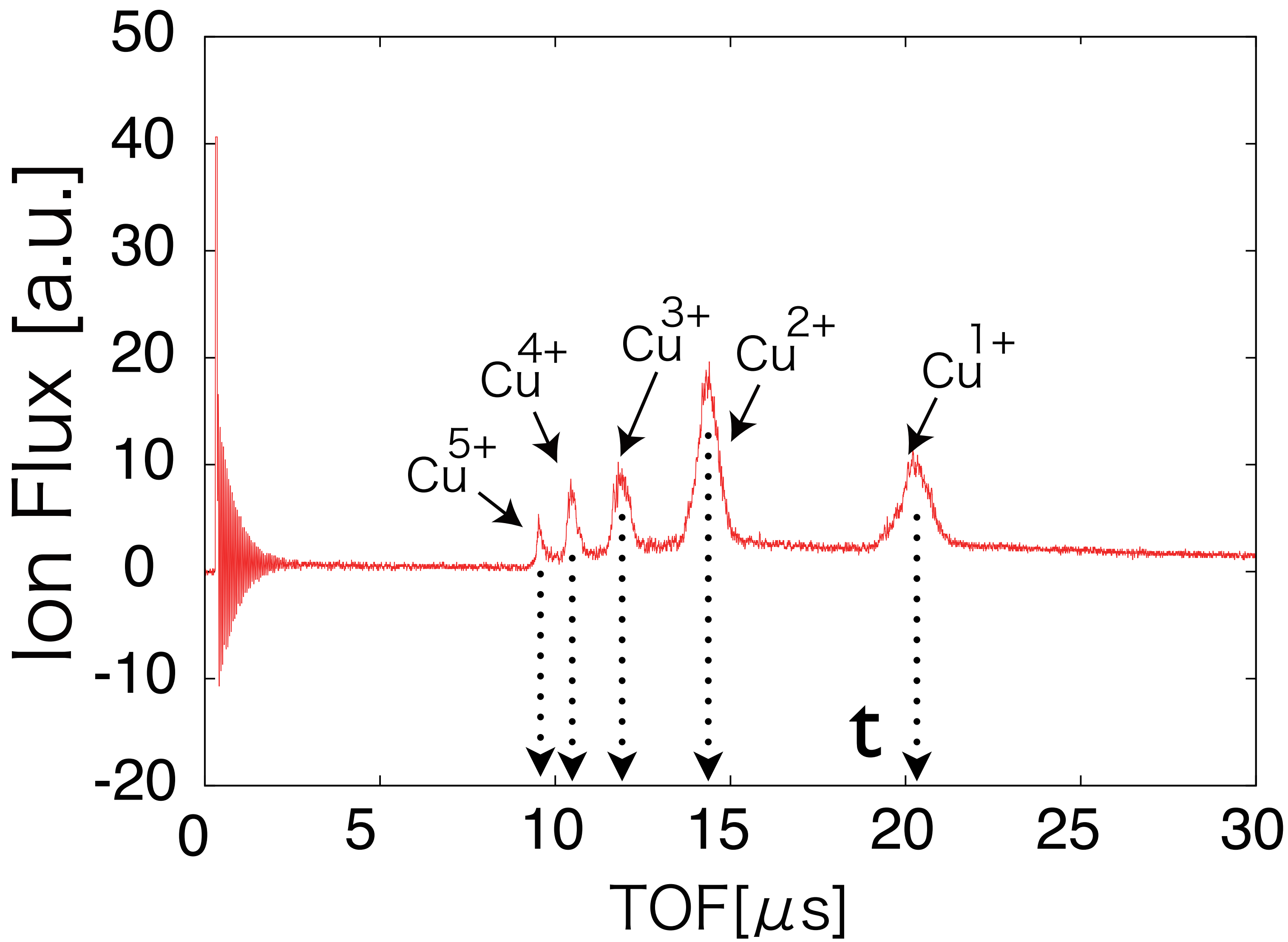
- Fast peak appeared in magnetic field had a very narrow angular distribution, corresponding $\cos^{300}\theta$
- At *x* =17 mm, TOF spectra were similar to those without magnetic fields.

Ion energy analyzer

The distance L from the target to the electron multiplier is 610 mm and 850 mm



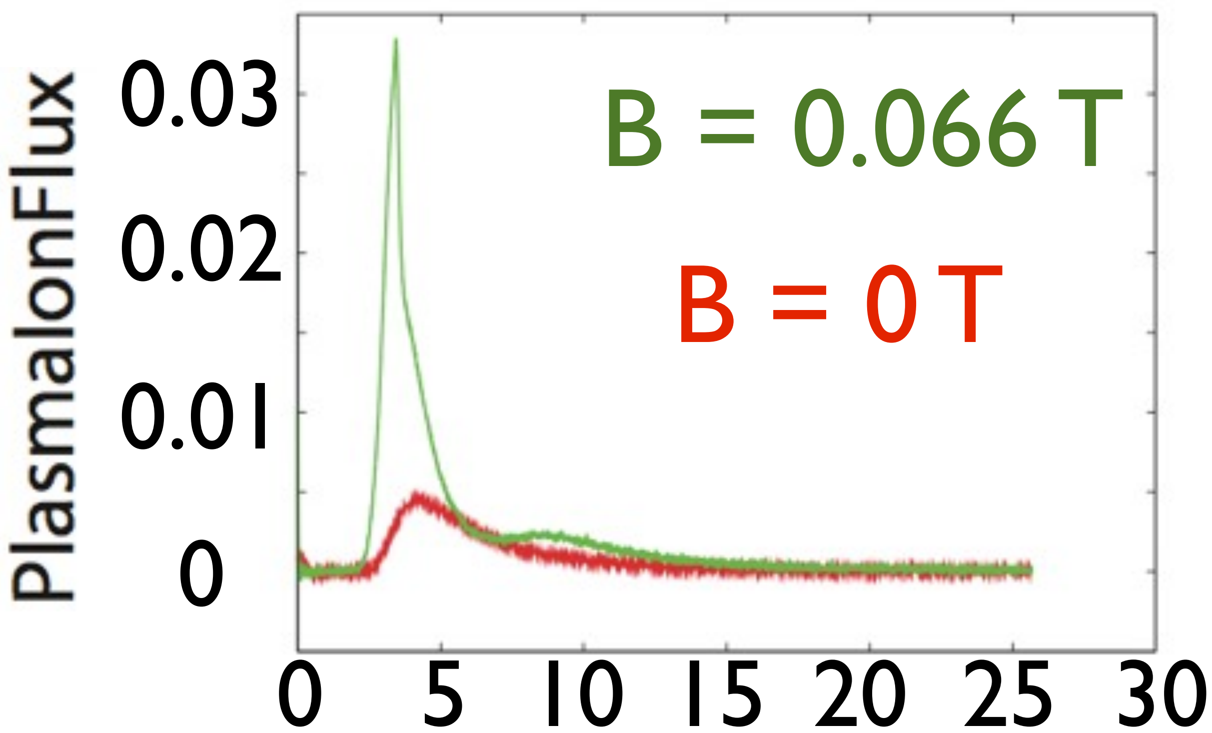
Typical signal of ion energy analyzer



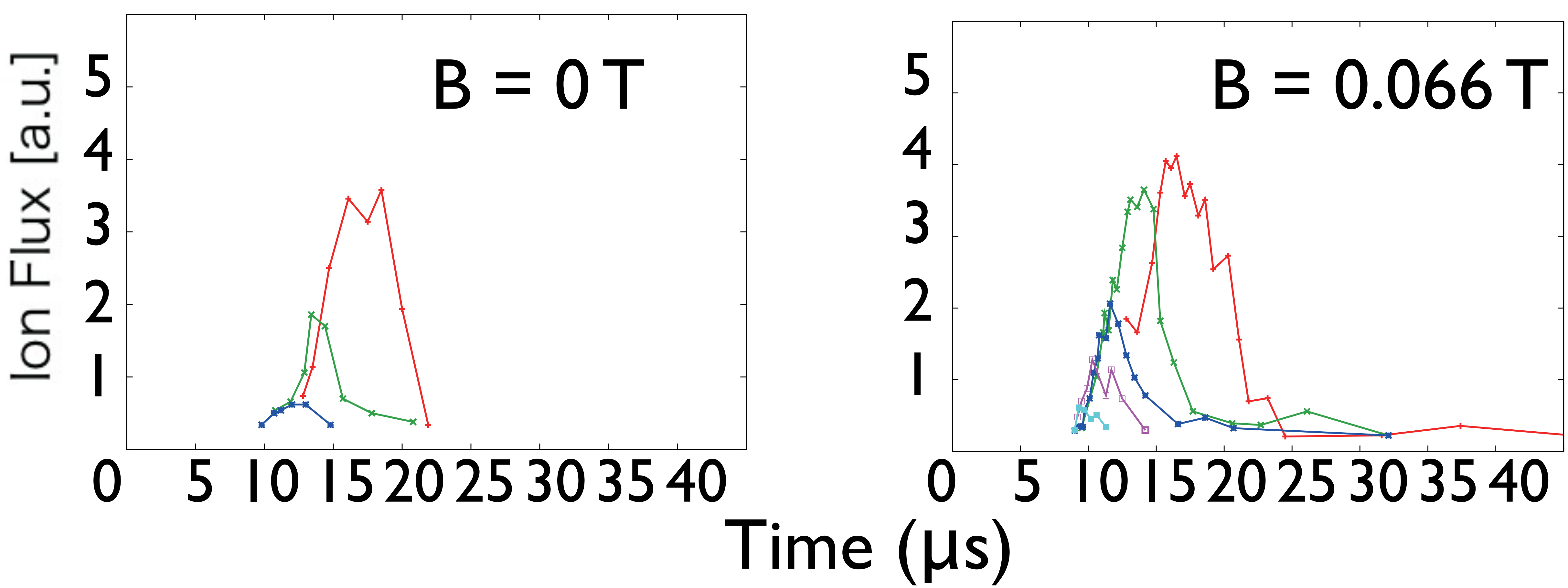
$$\frac{M}{z} = \frac{t^2 eU}{L^2 \ln(R_1/R_2)}$$

identify the ion
and
obtain the ion flux spectra

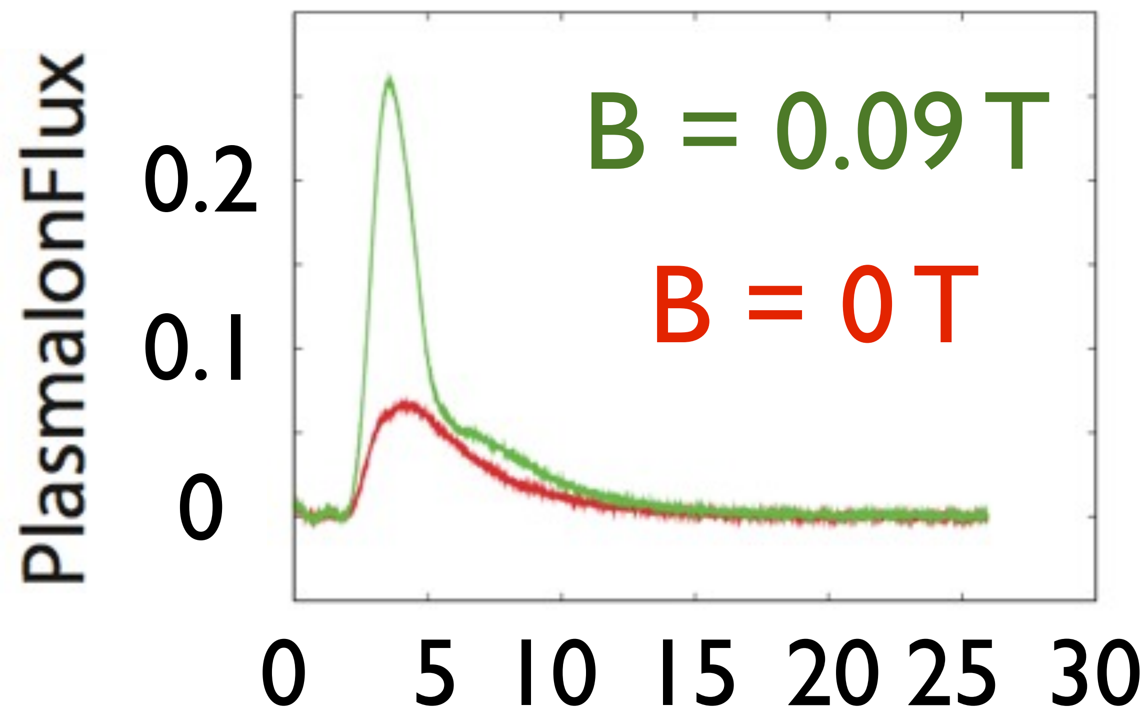
Result of ion energy analysis at $E_L = 3.2 \times 10^8$ W/cm^2, B = 0.066 T, L = 850 mm



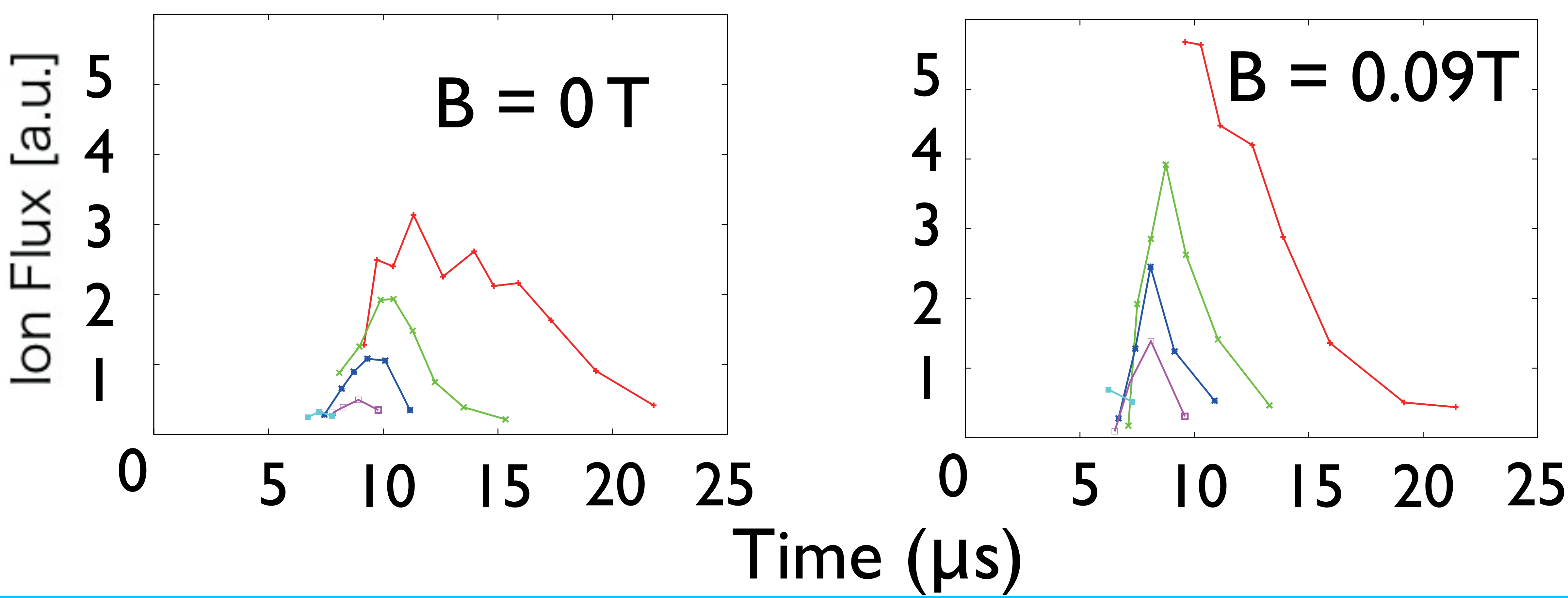
- The additional fast peak was composed of highly charged ions.
- Higher charged ions were faster and more increased.



Result of ion energy analysis at $E_L = 9.5 \times 10^8$ W/cm^2, B = 0.09 T , L = 610 mm



- The highly charged ions increased too, but more slightly.
- Singly-charged ion more increased (1.1 times→2times).



Summary

We investigated the effect of the magnetic field on the laser ablation plasma and observed the following effects.

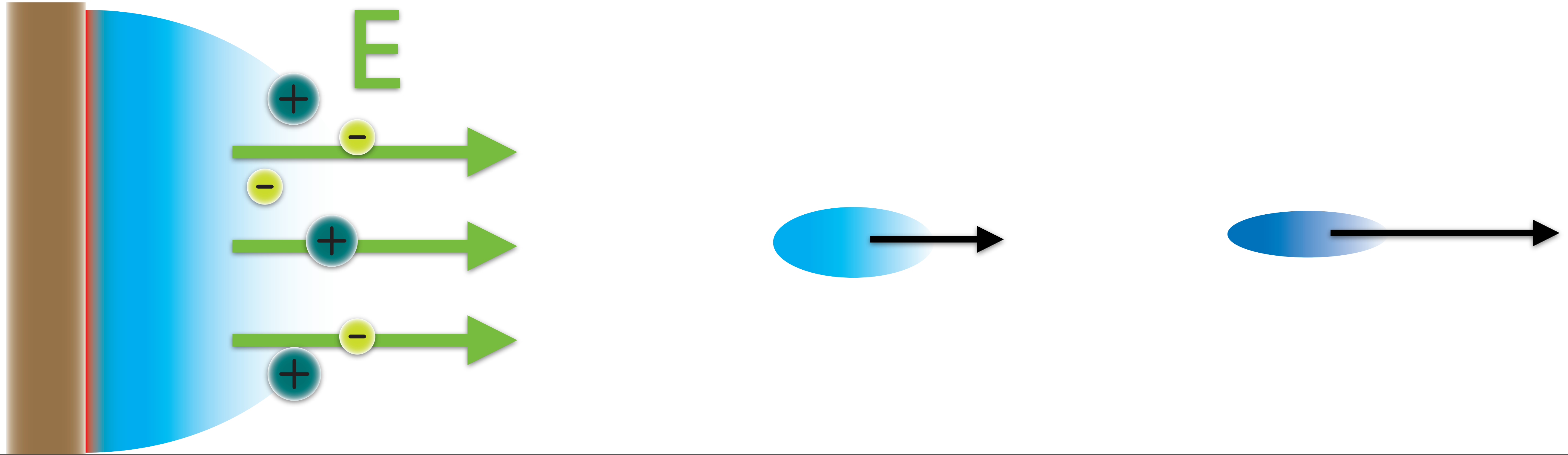
- Additional fast peak appeared with weak magnetic field.
- The fast peak increased drastically, then decreased slowly and became wider with increasing magnetic field.
- The fast peak had a very narrow angular distribution
- The fast peak was composed of highly charged ions.

- Slow peak appeared and increased with the magnetic field.

Discussion 1 : formation of electric field

Additional fast peak composed of highly charged ions and its very sharp angular distribution indicate that

•presence of electric field that accelerate the ions
•the electric field become directional by the longitudinal magnetic field.

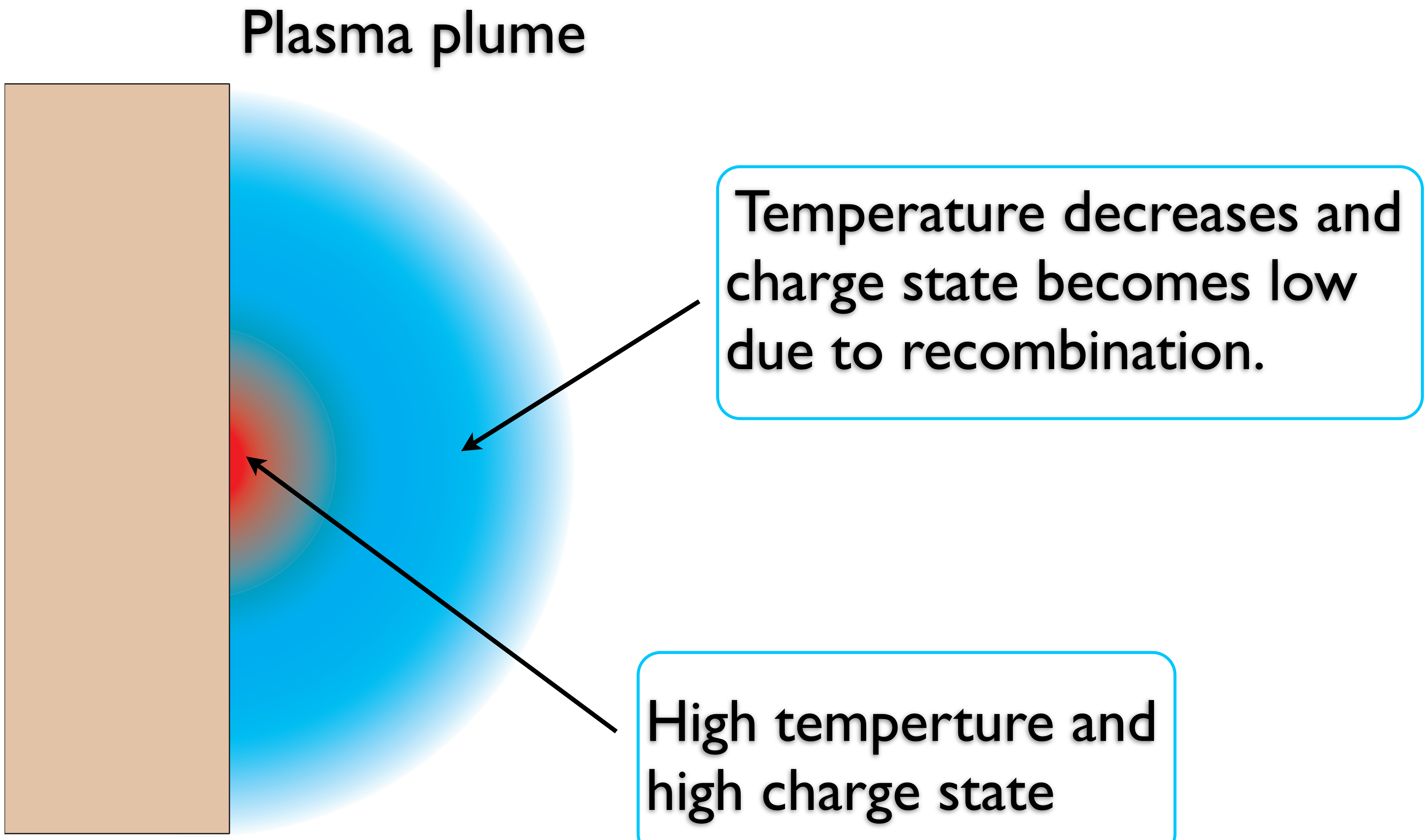


Discussion 2 : increase of recombination

Increase of slow peak and the spread of the fast peak indicate that

- the magnetic field increases the collision frequency and sets on the recombination.

Discussion 2 : increase of recombination



Conclusion

Followings were indicated

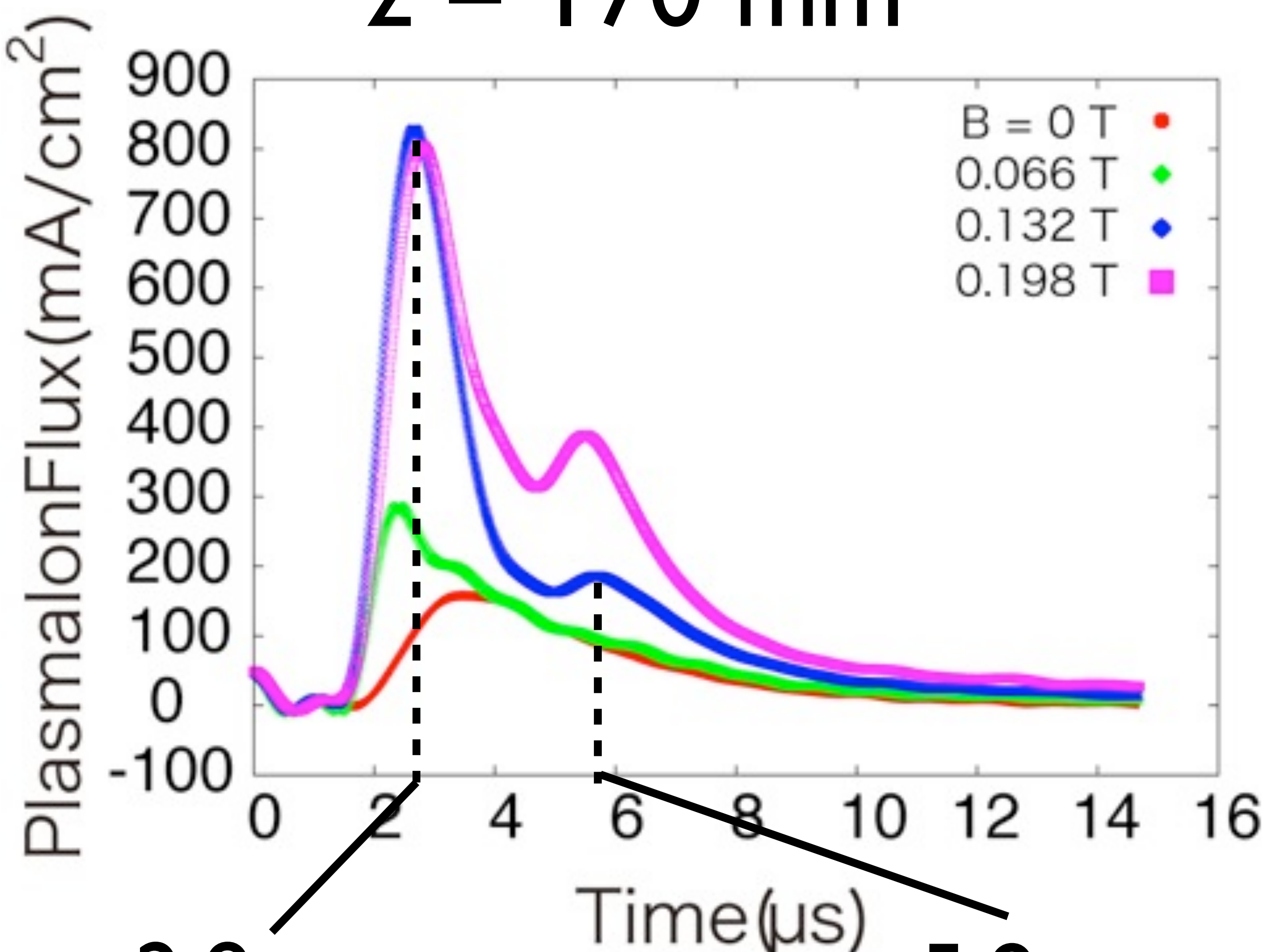
By the axial magnetic field;

- Directional electric field is formed.

- Recombination increases.

The plasma flux as a function of the distance at $E_L = 9.5 \times 10^8$ W/cm^2

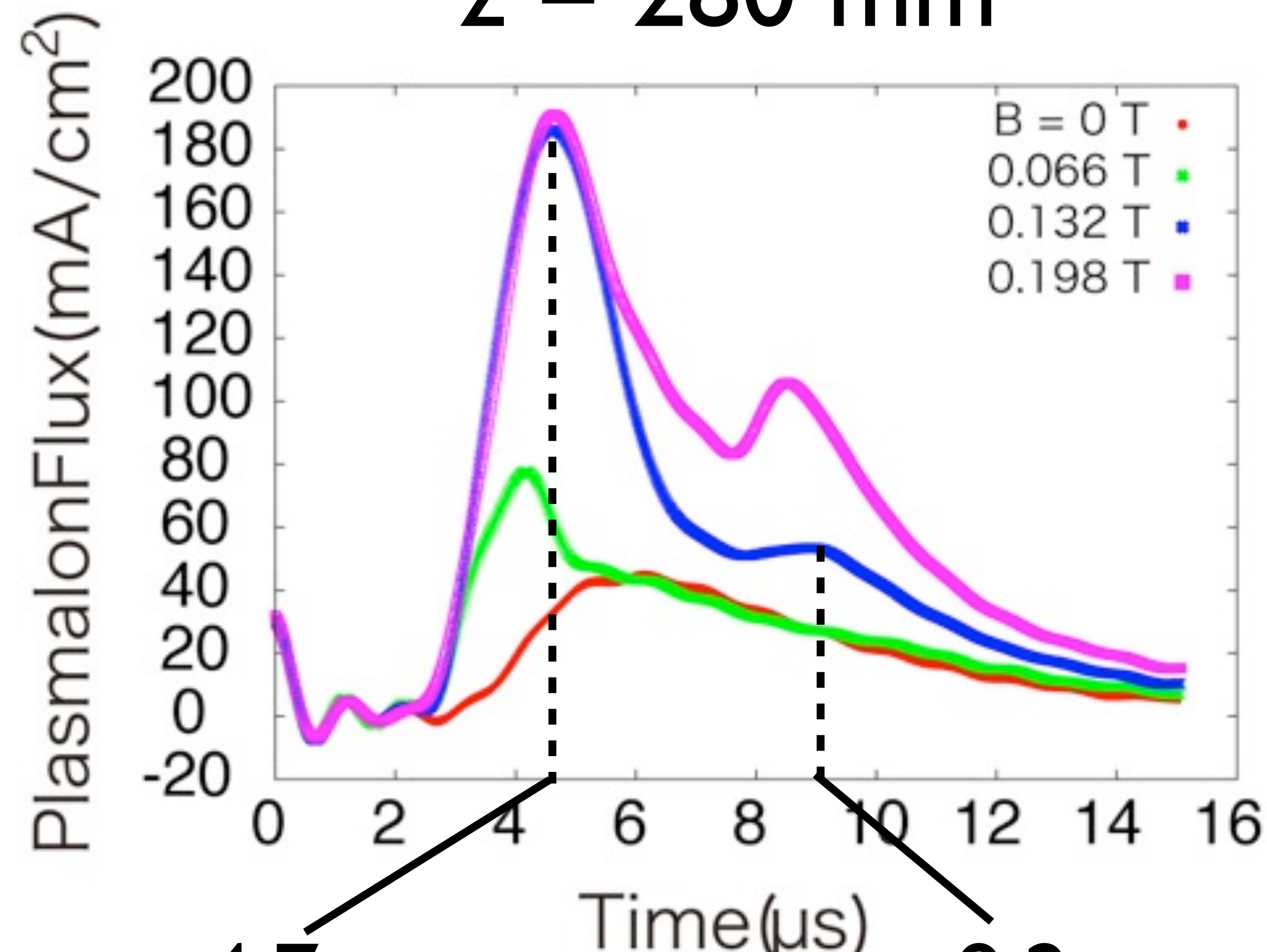
z = 170 mm



2.8 μs → 6.0 cm/μs (1.2 keV)

5.8 μs → 2.9 cm/μs (300 eV)

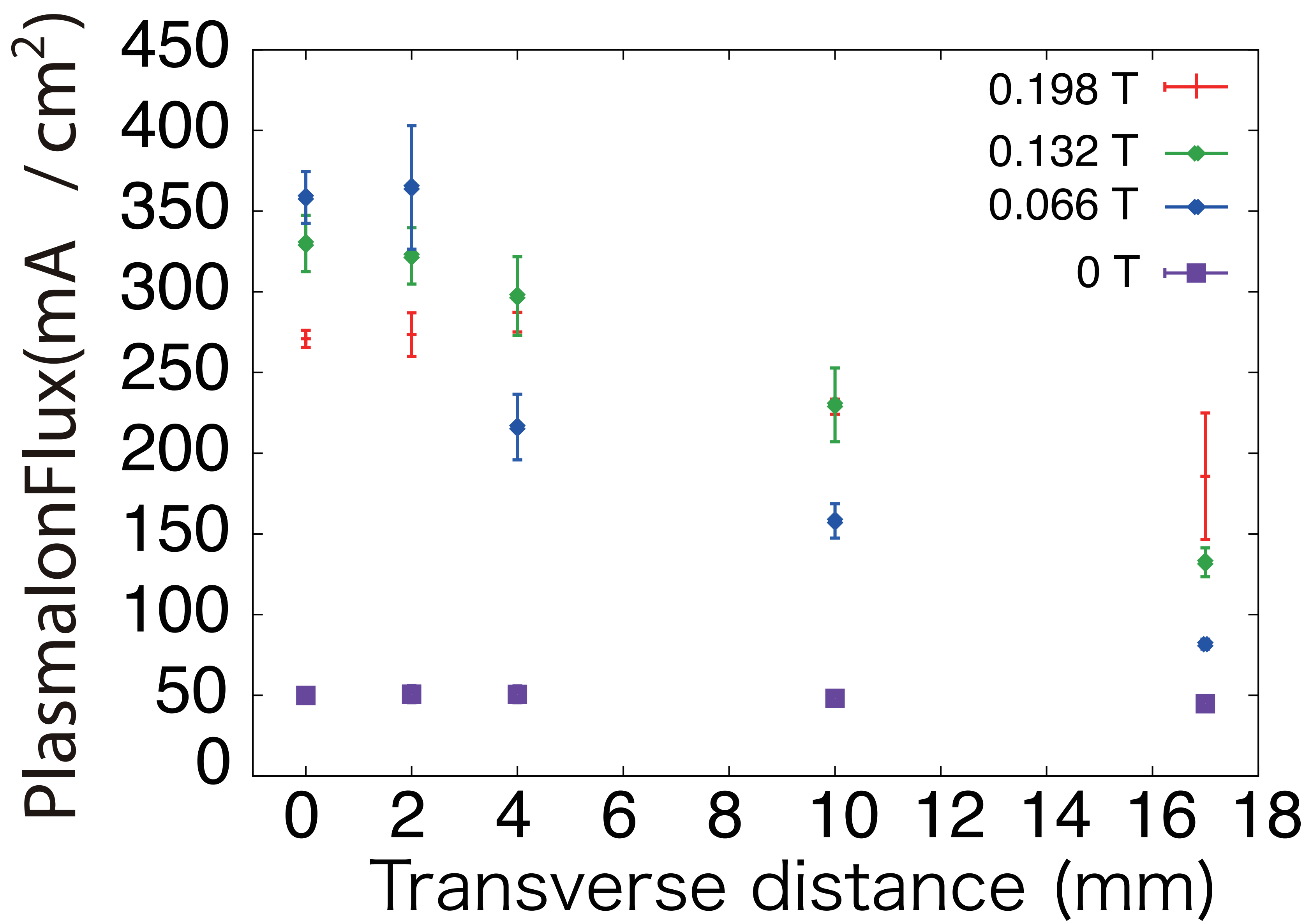
z = 280 mm



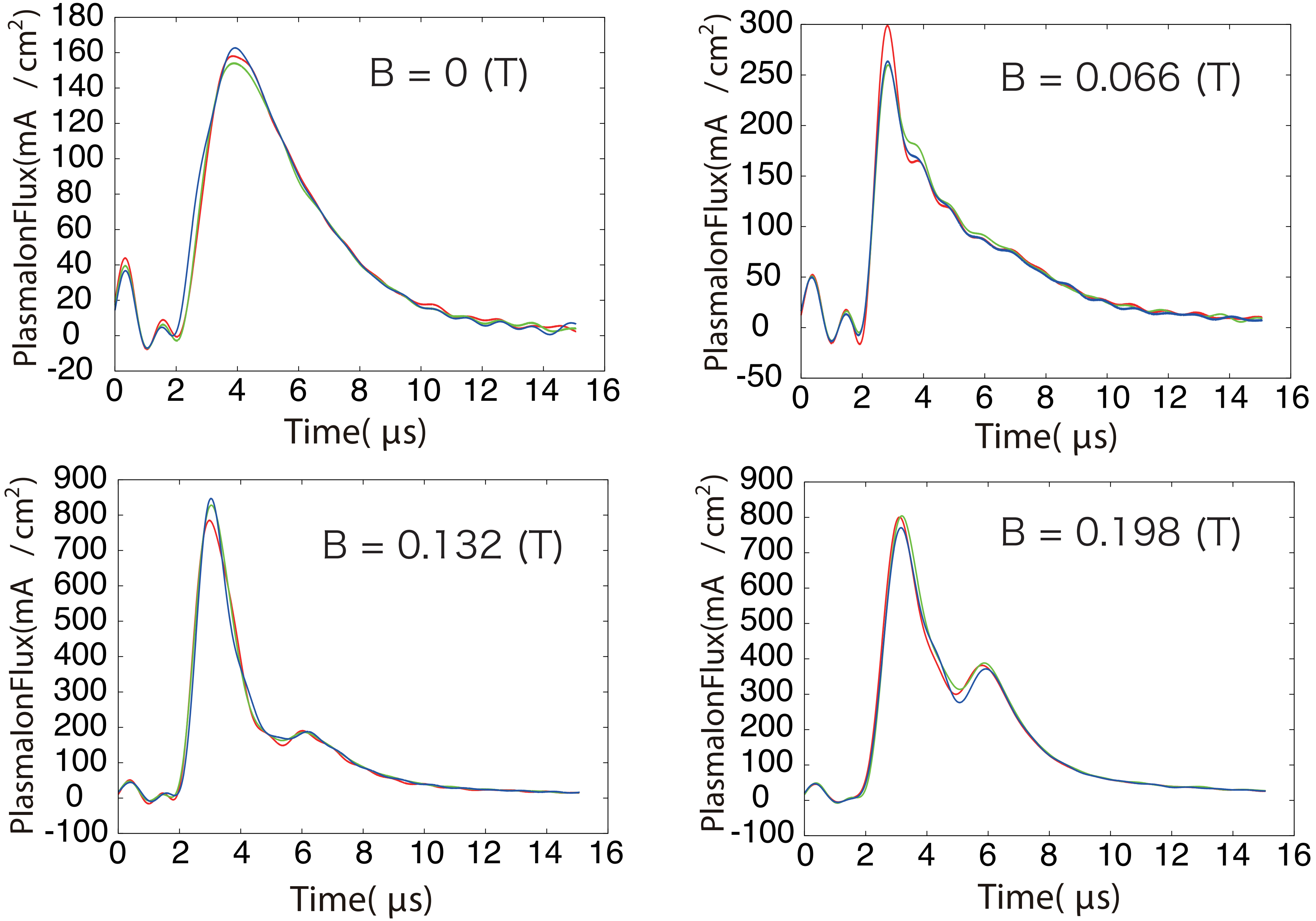
4.7 μs → 6.0 cm/μs

9.2 μs → 3.0 cm/μs

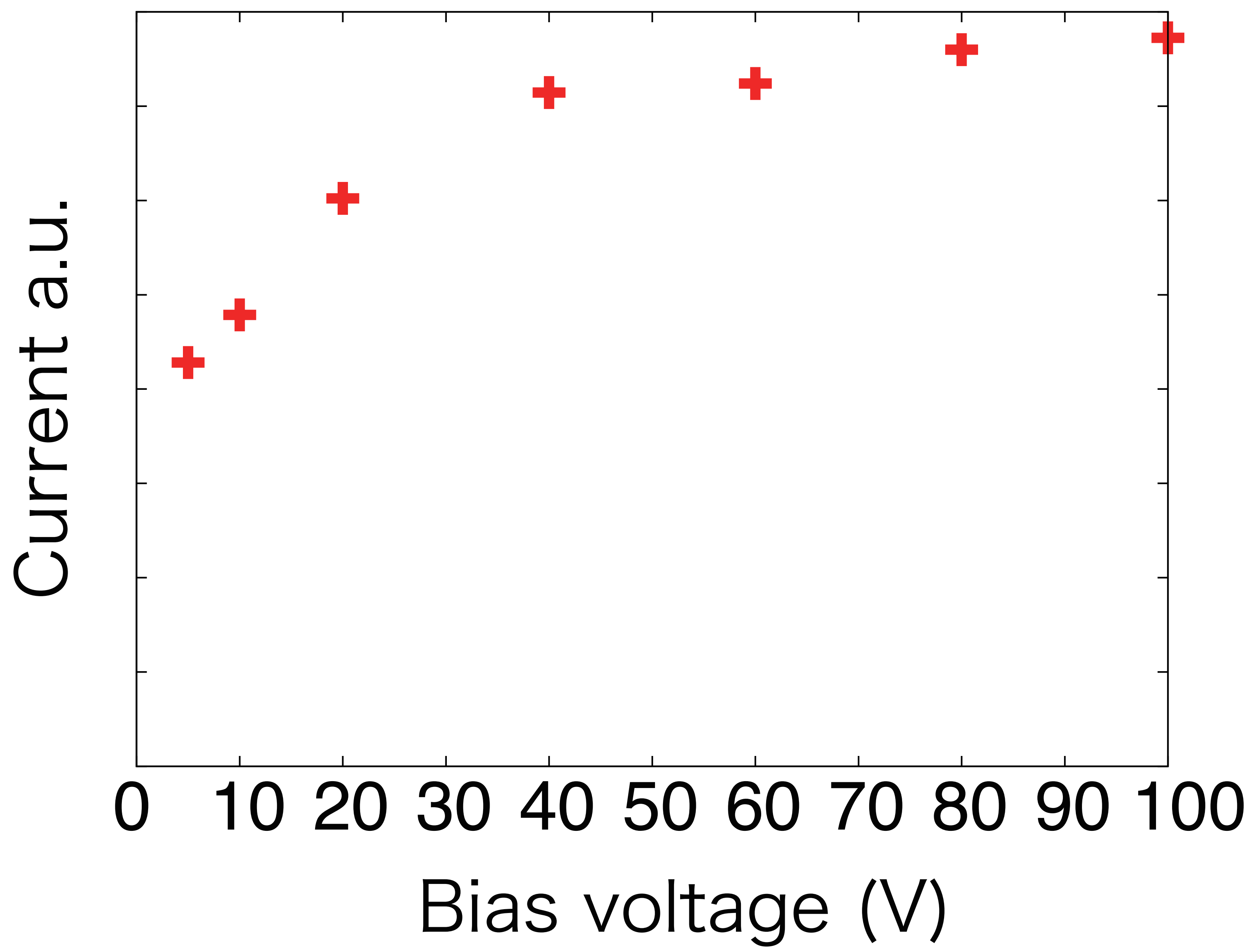
The transverse distribution at z = 170 mm, $E_L = 3.2 \times 10^8$ W/cm^2



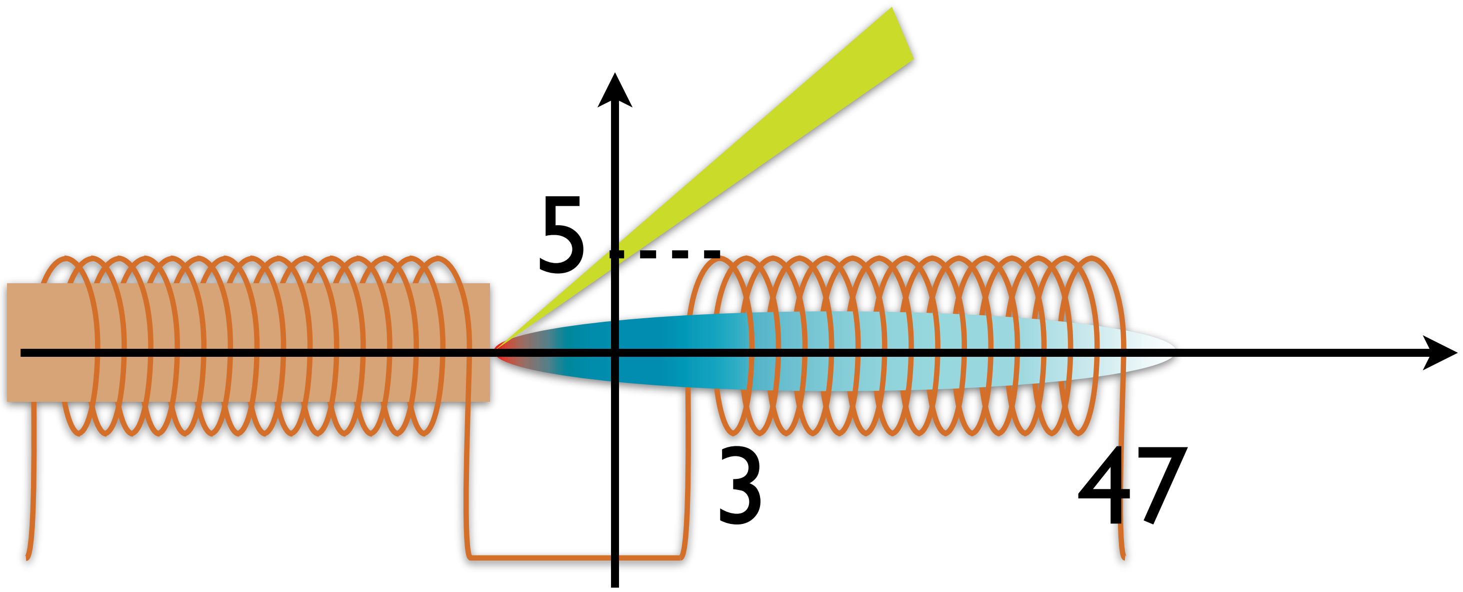
Reproducibility of the signal of the biased plate (at z = 170 mm, $E_L = 9.5 \times 10^8$ W/cm^2)

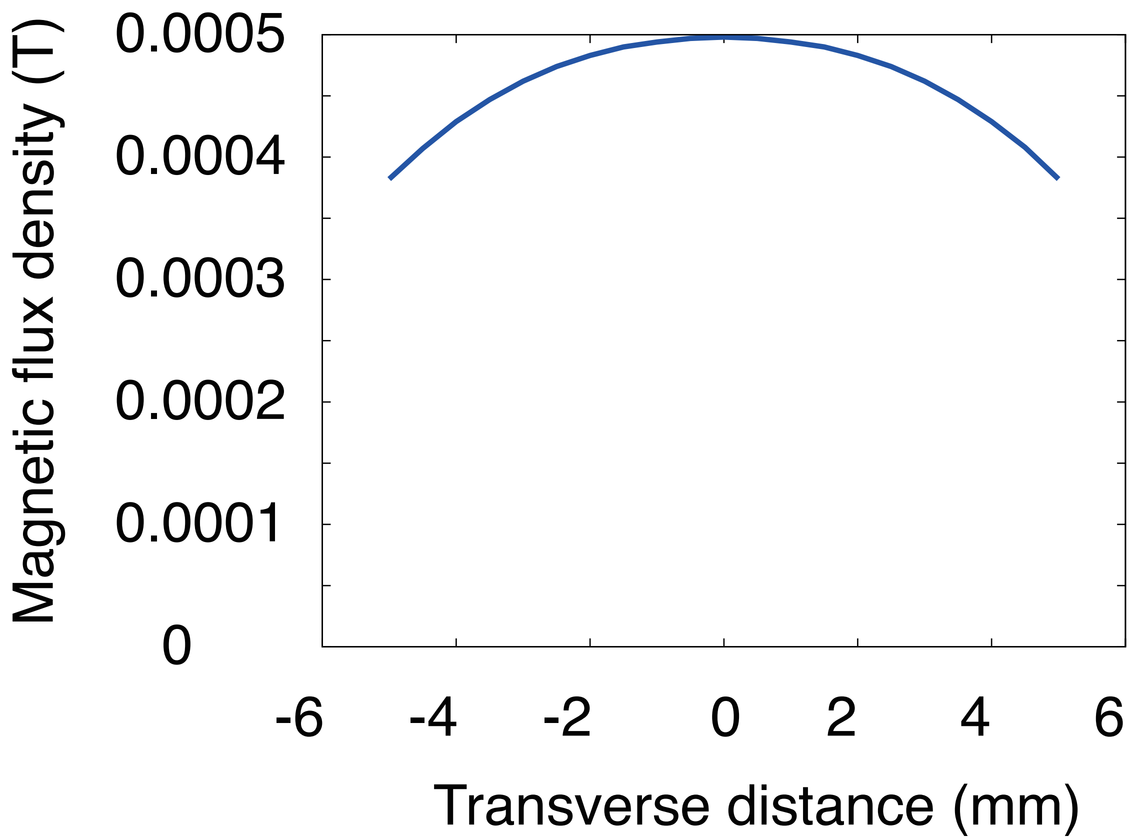


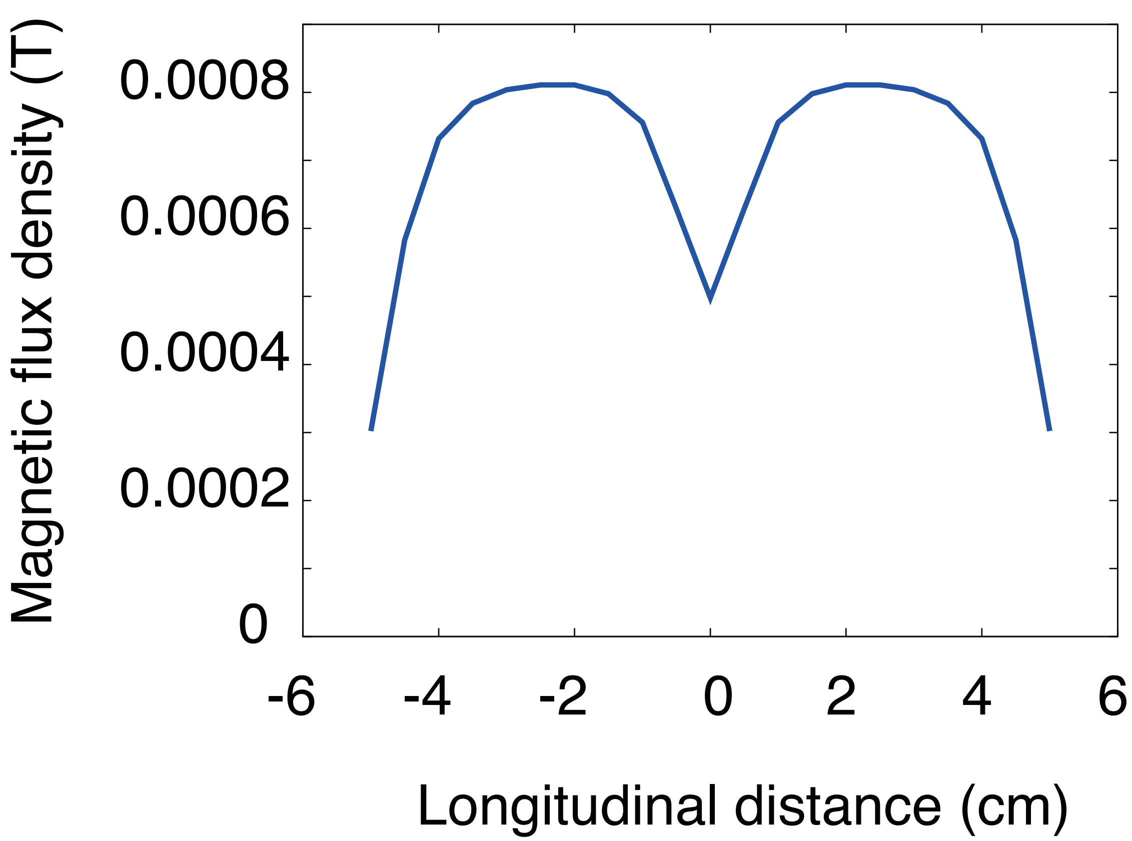
Dependency of the peak flux on bias voltage



The magnetic configuration estimated by numerical calculation







Electrostatic Energy Analyzer